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**ABERDEEN PROVING GROUND
MARYLAND**



BALLISTIC RESEARCH LABORATORY

REPORT

**EFFECT OF VARIOUS DRIVING BANDS ON THE AERODYNAMIC
PERFORMANCE OF PROJECTILES AT HIGH VELOCITIES**

BY

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Ordnance Research and Development Center Project No. 4652

Stein/jsm
Aberdeen Proving Ground, Md.
19 February 1946

EFFECT OF VARIOUS DRIVING BANDS ON THE AERODYNAMIC
PERFORMANCE OF PROJECTILES AT HIGH VELOCITIES

Abstract

This report compares the drag and moment coefficients at high velocities of a series of similar projectiles with varying driving band shapes. Included is a projectile without any driving band. The data was obtained from firings in the Aerodynamics Range. A variation of K_M with yaw is observed and its magnitude evaluated.

Object:

The purpose of the research reported on was to study the effect of different types of banding on the aerodynamic performance at high velocities of two particular projectile shapes. This program was carried out in cooperation with the Franklin Institute, and the basic projectile shapes and types of banding were suggested by the Institute. The firings were carried out in the Aerodynamics Range at the Ballistic Research Laboratory, using the full complement of sixteen spark photograph stations and the accompanying chronograph equipment.

Design:

The projectiles were fired from a special gun 85" long, having 0.490" diameter bore and a depth of rifling of 0.010". This is twice the depth of normal caliber 0.50 rifling. The gun uses a special 20mm breech with a large chamber, which makes it possible to get velocities close to 4000 feet per second using pre-engraved steel projectiles. All the projectiles used in this investigation were pre-engraved.

The C-28 type represents one of the shapes used in the program (Figure 1a). This projectile has a driving band one-half a caliber wide with a tapered leading edge. The C-41 type has the same body shape as the C-28, but has a band one and one-half calibers wide (Figure 1b). The leading edge of each land is sharpened to make possible the use of pre-engraved bands in automatic weapons. The performance of these two projectiles was covered in Ballistic Research Laboratory Memorandum Report No. 365, "Effects Upon the Moment and Drag Coefficient of an Increase in Width of the Driving Band" (by William A. Siljander).

The other shape used is characterized by the bandless C-43 type, which has a short tangent radius ogive with a meplat one-quarter of a caliber in diameter, and a short boattail (Figure 2a). This type was fired using a sabot to impart spin to the projectile. There are six other types based on this shape. The C-39 has a driving band which simulates the kind used in conventional artillery. The band is about one caliber wide and has a tapered leading edge (Figure 2b). The C-33 has a band one-half a caliber wide with a blunt leading edge, and is set in the normal position along the body (Figure 2c). Types C-30 and C-34 are identical except for center of gravity position. They have a band

one and one-half calibers wide with sharpened lands (Figure 2d). Type LI-200 has a single narrow band (3/4 caliber) with square leading edge set forward on the body (Figure 3a). Type LI-107 combines the bands of the C-33 and the LI-200 (Figure 3b).

To determine how effective the short boattail is at these high velocities Type C-31 was fired. This projectile is the same as the C-33 except that it has no boattail.

Procedure:

The eight projectile types covered in this report were all fired at a single velocity, 3600 feet per second, with the exception of the C-34 which was also fired at 2500 feet per second, in order to give a first approximation of the variation of K_D and K_M with velocity. In the actual firings there was a slight dispersion around the desired velocity, but by using the results from the C-34 type K_D and K_M for each round were corrected to a Mach number of 3.200.

The experimental data giving time and distance throughout the range was reduced in the conventional manner. Time was considered a power series in distance with all terms past the cubic neglected. The coefficients of the series were determined by a least squares process. K_D was then computed from these coefficients together with the physical characteristics of the projectiles and the air.

To find the shape of the K_{D0} vs Mach number curve for type C-34 the effect of yaw was first taken out. To do this the slope of the K_{D0} vs Mach number curve at $M = 3.200$ was estimated and all rounds brought to this common Mach number. The drag coefficients were then plotted as a function of the mean squared yaw. The following relation was obtained and used to take out the effect of yaw.

$$K_{D0} = K_D - 0.0010 \bar{\delta^2} \quad (1)$$

where K_D is the value of the drag coefficient without any correction, K_{D0} is its value at zero yaw, and $\bar{\delta^2}$ is the mean squared yaw in square degrees. The corrected drag coefficients were then fitted by a least squares

process to the following expression:*

$$Q = \sqrt{1 + M^2 K_{DO}^2} = a + bM \quad (2)$$

where a and b are coefficients which depend on the particular shell and are determined from two or more values of K_{DO} and M . Equation (2) was solved for K_{DO} giving

$$K_{DO} = b^2 + \frac{2ab}{M} + \frac{a^2-1}{M^2}. \quad (3)$$

The slope of the above curve at $M = 3.200$ was found and used for making the velocity correction on the K_D data.**

The epicyclic yawing motion of each projectile was analyzed to find the moment coefficient, which is defined as

$$K_M = \frac{\text{Moment}}{\rho v^2 d^3 \sin \delta} \quad (4)$$

where ρ is the air density, v is the velocity, d the caliber of the projectile, and δ is the angle of yaw. The analysis is based on the theory which is given in Ballistic Research Laboratory Report No. 446, "On the Motion of a Projectile with Small or Slowly Changing Yaw" by Kelley and McShane. According to this first order theory, K_M is proportional to the product of the angular rates of the epicyclic arms of the motion, and is independent of the yaw. An examination of the results, however, seemed to indicate a systematic dependence of K_M on the yaw.

If the assumption is made that K_M as found here is some function of δ such that the first derivative is zero when $\delta = 0$ (in other words the theory holds at very small angles), and is independent of the sign of the angle of yaw, then the following relation suggests itself.

* See Ballistic Research Laboratory Report No. 542, "Some Comments on the Form of the Drag Coefficient at Supersonic Velocities" (by R. N. Thomas).

** See Ballistic Research Laboratory Report No. 567, "Comparison of 155mm Shell Designs by Means of Model Firings" (by H. Stein) for a more detailed description of the procedure.

$$K_M = K_{M0} + \frac{A}{M} \delta^2 \quad (5)$$

where K_{M0} is the moment coefficient at zero yaw, and $\frac{A}{M}$ is the yaw-moment slope.

Before the above expression could be fitted to the data the effect of velocity was taken out. To express the variation of K_{M0} with Mach number, the following form has been found useful at supersonic velocities,

$$\sqrt{K_{M0}} = a + \frac{b}{M} \quad (6)$$

where a and b are coefficients which depend on the particular shell and are determined from two or more values of K_{M0} and M . The data from the C-34 firings was fitted to the above expression to get the approximate slope of the K_{M0} vs M curve at $M = 3.2$. Using this slope K_M for every round was corrected to $M = 3.2$ and then fitted to Equation (5) by a least squares process to find K_{M0} .

Results:

Drag

Fitting the K_{D0} data for type C-34 to the Q function (Table I) and solving for the slope of the K_{D0} vs M curve at $M = 3.2$, gives

$$\left. \frac{dK_{D0}}{dM} \right|_{M=3.2} = -0.021$$

Combining this with Equation (2),

$$K_{D0} = K_D - 0.0010 \delta^2 - 0.021 (3.200 - M). \quad (7)$$

The above equation was applied to the drag data (Table II) and gives the following results:

Type	Mean K_{D0}	P.E. of Mean K_{D0}	No. of Rounds
C-43	0.129	0.28%	6
C-39	0.132	0.23%	6
C-34	0.132	0.57%	4
LI-200	0.133	0.44%	5
C-33	0.134	0.51%	5
LI-107	0.136	0.32%	4
C-31	0.137	0.42%	6

Moment and Stability:

Using an estimated value for $\frac{dK_M}{dM} \bigg|_{M=3.2}$

equal to -0.20, all values of K_M were corrected to this common Mach number, and fitted to Equation (5) (Table III). The following results were obtained:

Type	K_{M0}	P.E. of K_{M0}	K'_M	P.E. of K'_M	No. of Rounds
C-43	1.21	0.36%	-0.00676	10.8%	6
C-39	1.19	0.63%	-0.00300	17.9%	6
C-33	1.17	0.38%	-0.00370	22.8%	4
C-30	1.20	0.29%	-0.00616	11.6%	4
C-34	1.68	0.73%	-0.000535	360.0%	4
LI-200	1.22	1.9%	-0.00416	26.5%	5
LI-107	1.20	0.84%	-0.00518	94.6%	4
C-31	1.15	0.18%	-0.00442	17.2%	6

Reducing the K_M results for Type C-34 to zero yaw, fitting to Equation (6) and solving for $\frac{dK_M}{dM}$ at $M = 3.2$ gives -0.202 (Table I). This agrees well with the originally estimated value.

From K_M for types C-30 and C-34 which differ only in center of gravity position, the following values of K_N and center of pressure position were obtained:

$$K_N = 1.19 \pm 2.6\%$$

C.P. = 3.04 calibers from base.

Taking a weighted mean of the various values of K'_M , using

$\frac{1}{(P.E.)^2}$ as the weight of each quantity gives

$$\frac{K'}{M} = -0.00461 \pm 6.3\%.$$

Analysis:

Drag:

The K_{D0} for the bandless C-43, which is the basic shape, is 0.129. The addition of a conventional band (C-33) or a wider pre-engraved band with sharpened lands (C-34) added 0.003 to the K_{D0} . If the leading edge of the band is square (C-33), LI-200, the effect is a little larger. The double band of the LI-200 increased the drag by 80% of the sum of the drags of the two bands. An examination of the spark photographs shows strong shocks off both bands so that they are both about equally responsible for the increase.

The drag coefficient for the C-31 which has no boattail is 0.003 higher than for the C-33 with boattail. This indicates that the small boattail even at this relatively high Mach number is still effective in reducing drag.

It is interesting to calculate a drag coefficient for a band alone. If drag coefficient for the band is defined as

$$K_D = \frac{\text{Band Drag}}{\rho v^2 A} \quad (8)$$

where A is the frontal area of the band, then for type C-33 K_D (Band) equals 0.0764. If stagnation pressure (based on the undisturbed air) were acting on the band, K_D (Band) would be about 12 times this value.

It should be noted that this type of projectile has a relatively high drag coefficient compared to modern streamlined projectiles. The form factor is about 1.5 with respect to projectile type 2 (Figure 4).

Moment and Stability:

The stability varied only slightly between types. The projectiles all had stability factors around 1.7. The variation in K_{M0} from one type to another may be caused by variation in center of gravity position, variation in

center of pressure position, and changes in the size of K_N . The actual differences encountered in this program were probably caused by combinations of all three.

If the actual flow around a projectile is assumed to be made up of an axial flow and a cross flow, it is clear that the increased area at the band will cause an increase in the aerodynamic force over the force on the bandless shell. This local increase in the force will effect the moment coefficient. Since the total center of pressure is ahead of the center of gravity, putting the band ahead of the center of gravity will increase K_{MO} and putting it behind the center of gravity will decrease K_{MO} .

The present firings show this effect clearly. K_{MO} for the bandless C-43 is 1.21. Type C-36 which has the band furthest back has the lowest K_{MO} of the projectiles with boattails. Type LI-200 which has the band near the front of the body, ahead of the center of gravity has the highest K_{MO} . Type C-31 which has no boattail has the lowest K_{MO} .

The variation of K_M with yaw is interesting. If K_M and k_m are defined as

$$K_M = \frac{\text{Moment}}{\rho v^2 d^2 \sin \delta} \quad (9)$$

$$k_m = \frac{\text{Moment}}{\rho v^2 d^3} \quad (10)$$

then $k_m = K_M \sin \delta \quad (11)$

or for small angles $k_m = K_M \delta \quad (12)$

and $\frac{dk_m}{d\delta} = K_M + \delta \frac{dK_M}{d\delta} \quad (13)$

It has generally been assumed that for small angles of yaw the last term in equation (13) is zero, and that therefore K_M is independent of the yaw. The present investigation seems to indicate that equation (12) should be,

$$k_m = K_{MO} \delta + K_M \delta^3 \quad (14)$$

and since K_M^1 is negative, k_m instead of being linear with yaw is concave down. A closer examination of the data from other programs seems to show this same effect. The combination of blunt projectile shapes and higher supersonic velocities may have exaggerated a condition which was small enough to escape notice in previous programs.

Conclusions:

Probably the most practical band shape would consist of a single pre-engraved band placed forward on the body similar to type LI-200. The leading edge of this band would be tapered in a manner similar to type C-39 or C-34. The shell would also have a rear bourrelet placed in the same position as the band in the C-33 type. If this rear bourrelet were faired into the body, it would not contribute materially to the drag, but combined with the front band would give good launching conditions. The forward position of the band would also provide a longer useful life for the gun as tests at the Franklin Institute have demonstrated.

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TABLE I

C-34

Round No.	Mach No.	K _D	K _M	$\overline{\delta^2}$ sq. deg.	K _{DO}	K _{MO}
966	2.948	0.1392	1.748	3.427	0.1357	1.746
967	3.155	0.1373	1.678	2.142	0.1352	1.677
968	3.115	0.1442	1.693	11.17	0.1330	1.657
969	3.077	0.1401	1.687	5.619	0.1345	1.654
1182	2.075	0.1648	2.037	5.592	0.1592	2.034
1183	2.117	0.1725	2.038	15.70	0.1606	2.030
1184	2.098	0.1588	-	-	0.1568	-

$$Q = \sqrt{1 + M^2 K_{DO}} = 0.8671 \pm 0.2054M$$

(± 0.71%) (± 1.1%)

$$K_{DO} = 0.0434 + \frac{0.3614}{M} - \frac{0.2481}{M^2}$$

$$\left. \frac{d K_{DO}}{d M} \right|_{M=3.2} = -0.021$$

$$\sqrt{K_{MO}} = 1.039 \pm 0.3109M^{-1}$$

(± 0.68%) (± 2.3%)

$$K_{MO} = 1.060 + \frac{1.685}{M} + \frac{0.6775}{M^2}$$

$$\left. \frac{d K_{MO}}{d M} \right|_{M=3.2} = -0.202$$

TABLE II

C-43

Round No.	Mach No.	K_D	σ^2	K_{D0} at $M = 3.200$
1191	3.221	0.1361	8.840	0.1277
1192	3.164	0.1395	3.368	0.1304
1193	3.159	0.1335	2.287	0.1304
1194	3.173	0.1307	2.168	0.1280
1195	3.092	0.1349	5.112	0.1275
1196	3.213	0.1327	4.789	0.1282

$$\text{Mean } K_D = 0.1287$$

$$\text{P.E. of Mean} = 0.000366 = 0.29\%$$

C-39

963	3.248	0.1383	6.395	0.1334
964	3.279	0.1345	24.58	0.1316
965	3.154	0.1408	9.046	0.1308
1166	3.157	0.1390	5.043	0.1327
1167	3.232	0.1512	20.40	0.1315
1168	3.156	0.1366	2.326	0.1334

$$\text{Mean } K_{D0} = 0.1332$$

$$\text{P.E. of Mean} = 0.0003002 = 0.23\%$$

C-33

956	3.201	0.1394	4.847	0.1346
957	3.217	0.1335	(0.5)	0.1334
1171	3.172	0.1369	1.685	0.1346
1172	3.185	0.1385	8.822	0.1294
1173	3.161	0.1362	3.042	0.1323

$$\text{Mean } K_{D0} = 0.1329$$

$$\text{P.E. of Mean} = 0.0006512 = 0.49\%$$

C-34

966	2.948	0.1392	3.427	0.1305
967	3.155	0.1373	2.142	0.1342
968	3.116	0.1442	11.17	0.1313
969	3.077	0.1401	5.619	0.1319

$$\text{Mean } K_{D0} = 0.1320$$

$$\text{P.E. of Mean} = 0.0005333 = 0.40\%$$

(Table II)

LI-200

Round No.	Mach No.	K_D	d^2	K_{D0} at $d = 3.200$
1177	3.123	0.1515	17.88	0.1320
1178	3.143	0.1533	17.10	0.1350
1179	3.153	0.1552	23.55	0.1307
1180	3.153	0.1589	24.32	0.1331
1181	3.172	0.1503	19.44	0.1303
				Mean $K_{D0} = 0.1322$
				P.E. of Mean = 0.0005753 = 0.41%

LI-107

959	3.176	0.1396	1.560	0.1376
1174	3.134	0.1371	0.521	0.1354
1175	3.154	0.1393	3.536	0.1348
1176	3.169	0.1387	1.158	0.1369
				Mean $K_{D0} = 0.1362$
				P.E. of Mean = 0.0004375 = 0.32%

C-31

953	3.219	0.1405	5.931	0.1350
954	3.195	0.1363	0.915	0.1353
955	3.194	0.1571	19.56	0.1375
1163	3.168	0.1369	0.536	0.1377
1164	3.203	0.1397	1.112	0.1366
1165	3.217	0.1405	5.470	0.1354
				Mean $K_{D0} = 0.1366$
				P.E. of Mean = 0.0004214 = 0.31%

TABLE III

0-43

Round No.	Mach No.	K_M	δ^2	K_M at $M = 3.200$
1191	3.221	1.155	8.840	1.159
1192	3.194	1.154	8.368	1.147
1193	3.159	1.199	2.287	1.191
1194	3.173	1.207	2.163	1.202
1195	3.092	1.195	5.112	1.173
1196	3.213	1.178	4.799	1.181

$$K_M = 1.211 - 0.006764 \delta^2 \quad \text{C.G.} = 1.018" \text{ from base.}$$

(± 0.36%) (± 10.8%)

0-39

963	3.248	1.162	6.395	1.172
964	3.279	1.109	24.58	1.125
965	3.154	1.141	9.046	1.135
1166	3.157	1.188	5.443	1.179
1167	3.232	1.118	20.40	1.124
1168	3.156	1.203	2.326	1.194

$$K_M = 1.188 - 0.003000 \delta^2 \quad \text{C.G.} = 0.994" \text{ from base.}$$

(± 0.63%) (± 17.9%)

0-33

956	3.201	1.156	4.847	1.156
1171	3.172	1.166	1.685	1.160
1172	3.135	1.141	8.822	1.138
1173	3.161	1.176	3.042	1.168

$$K_M = 1.172 - 0.003695 \delta^2 \quad \text{C.G.} = 1.000" \text{ from base.}$$

(± 0.35%) (± 22.8%)

0-30

961	3.200	1.140	9.143	1.140
962	3.210	1.173	1.948	1.175
1169	3.182	1.200	0.723	1.196
1170	3.162	1.194	1.960	1.186

$$K_M = 1.196 - 0.006162 \delta^2 \quad \text{C.G.} = 0.992" \text{ from base.}$$

(± 0.29%) (± 11.6%)

(Table III)

C-34

Round No.	Mach No.	K_x	δ^2	K_x at $M = 3.200$
966	2.948	1.748	3.427	1.698
967	3.155	1.678	2.142	1.669
968	3.116	1.693	11.17	1.676
969	3.077	1.687	5.619	1.662

$$K_x = 1.679 - 0.0005346 \delta^2 \quad \text{C.G.} = 0.734" \text{ from base.}$$

(0.734) (360%)

LI-200

1177	3.123	1.148	17.88	1.133
1178	3.143	1.162	17.10	1.151
1179	3.153	1.138	23.55	1.129
1180	3.153	1.117	24.82	1.108
1181	3.172	1.154	19.44	1.148

$$K_x = 1.219 - 0.004155 \delta^2 \quad \text{C.G.} = 1.013" \text{ from base.}$$

(1.9%) ($\pm 26.5\%$)

LI-107

959	3.178	1.205	1.560	1.201
1174	3.134	1.193	0.321	1.180
1175	3.154	1.180	3.586	1.171
1176	3.169	1.211	1.158	1.205

$$K_x = 1.198 - 0.005184 \delta^2 \quad \text{C.G.} = 0.977" \text{ from base.}$$

($\pm 0.84\%$) ($\pm 94.6\%$)

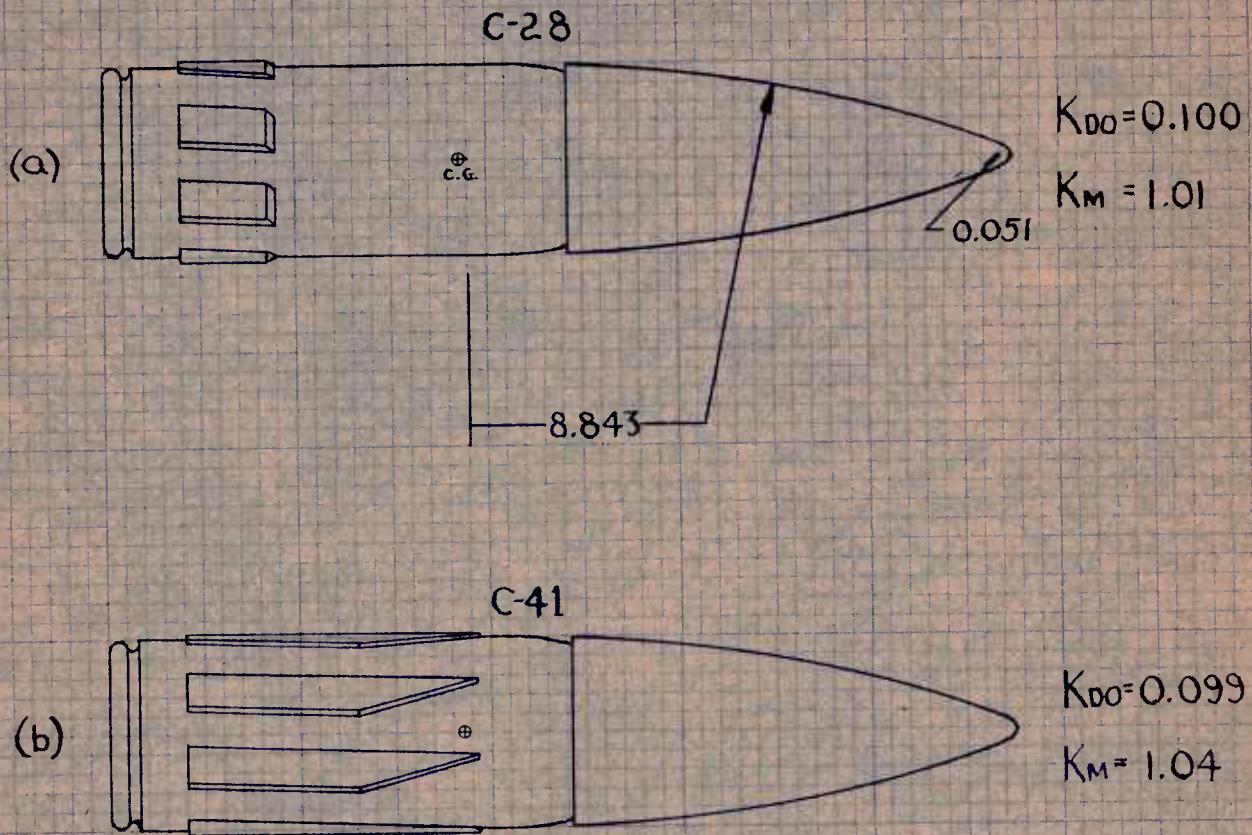
C-31

953	3.219	1.097	5.931	1.101
954	3.195	1.129	0.915	1.128
955	3.194	1.063	19.50	1.062
1163	3.168	1.145	0.536	1.139
1164	3.203	1.165	1.112	1.166
1165	3.217	1.130	5.470	1.133

$$K_x = 1.146 - 0.004421 \delta^2 \quad \text{C.G.} = 0.994" \text{ from base.}$$

($\pm 0.18\%$) ($\pm 17.2\%$)

ALL DATA GIVEN IS FOR A MACH NUMBER OF 3.200



ALL DIMENSIONS ARE IN CALIBERS

SCALE 1" = 1 CALIBER

FIGURE 1

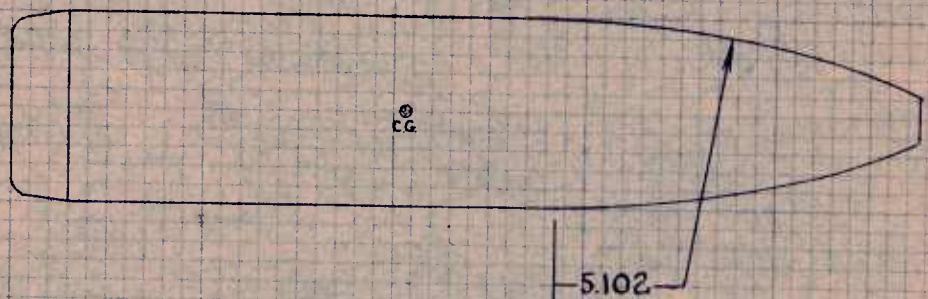
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ALL DATA GIVEN IS FOR A MACH NUMBER OF 3.200

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C-43

(a)

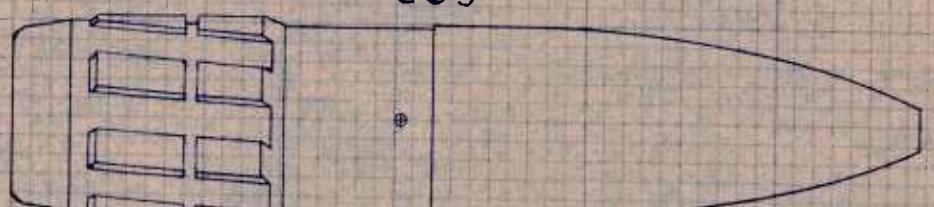


$$K_{D0} = 0.129$$

$$K_{M0} = 1.21$$

C-39

(b)

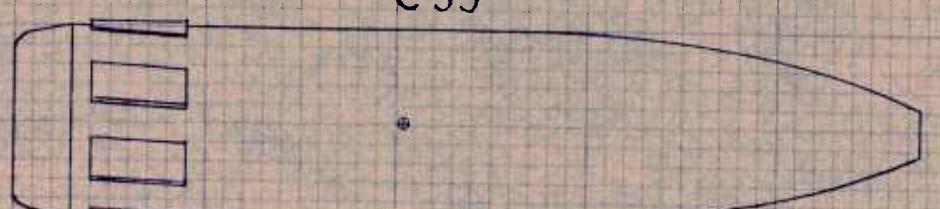


$$K_{D0} = 0.132$$

$$K_{M0} = 1.19$$

C-33

(c)

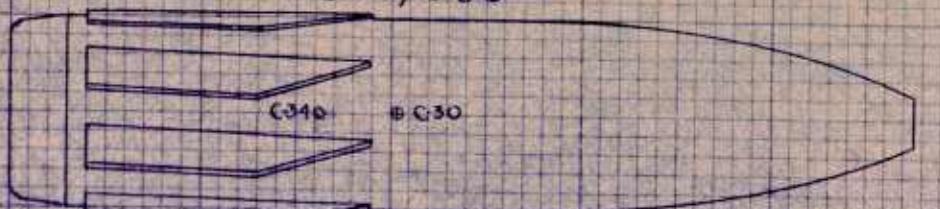


$$K_{D0} = 0.134$$

$$K_{M0} = 1.17$$

C-34, C-30

(d)



$$K_{D0} = 0.132$$

$$K_{M0} = 1.68$$

$$K_{M0} = 1.20$$

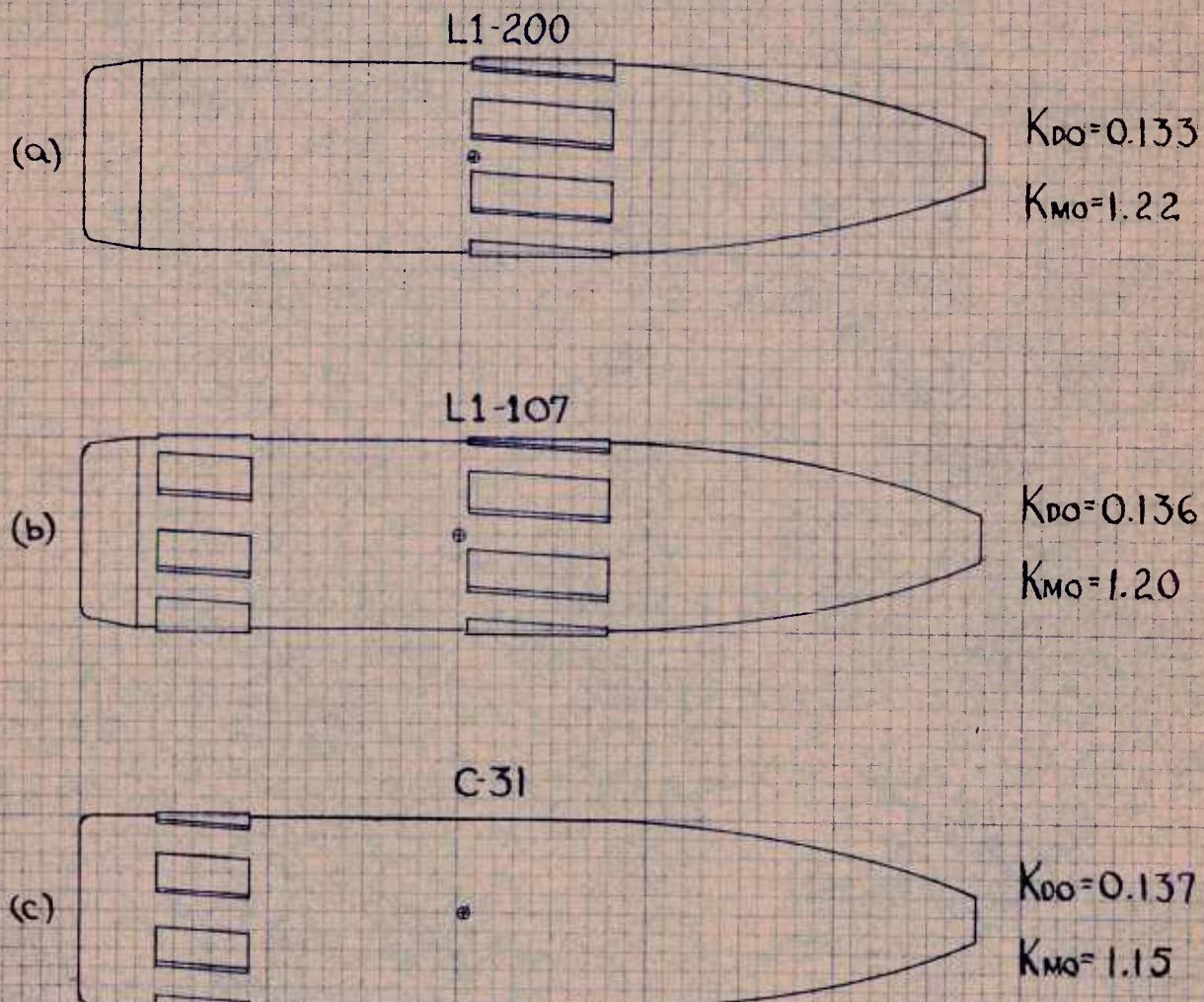
ALL DIMENSIONS ARE IN CALIBERS

SCALE 1" = 1 CALIBER

FIGURE 2

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ALL DATA GIVEN IS FOR A MACH NUMBER OF 3.200



ALL DIMENSIONS ARE IN CALIBERS

SCALE .1" = 1 CALIBER

FIGURE 3

K_{DO} vs MACH NUMBER
for PROJECTILE TYPE C 34 / .490
COMPARED WITH PROJECTILE TYPE 2

C-34

0.16

0.14

0.12

K_{DO}

0.10

0.08

0.06

1.6

1.8

2.0

2.4

2.6

2.8

3.0

3.2

MACH NUMBER

TYPE 2

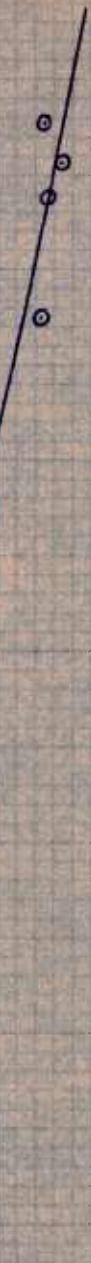


FIGURE 4

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KM VS. MEAN SQUARED YAW
FOR PROJECTILE TYPE C43/490
AT M = 3.200

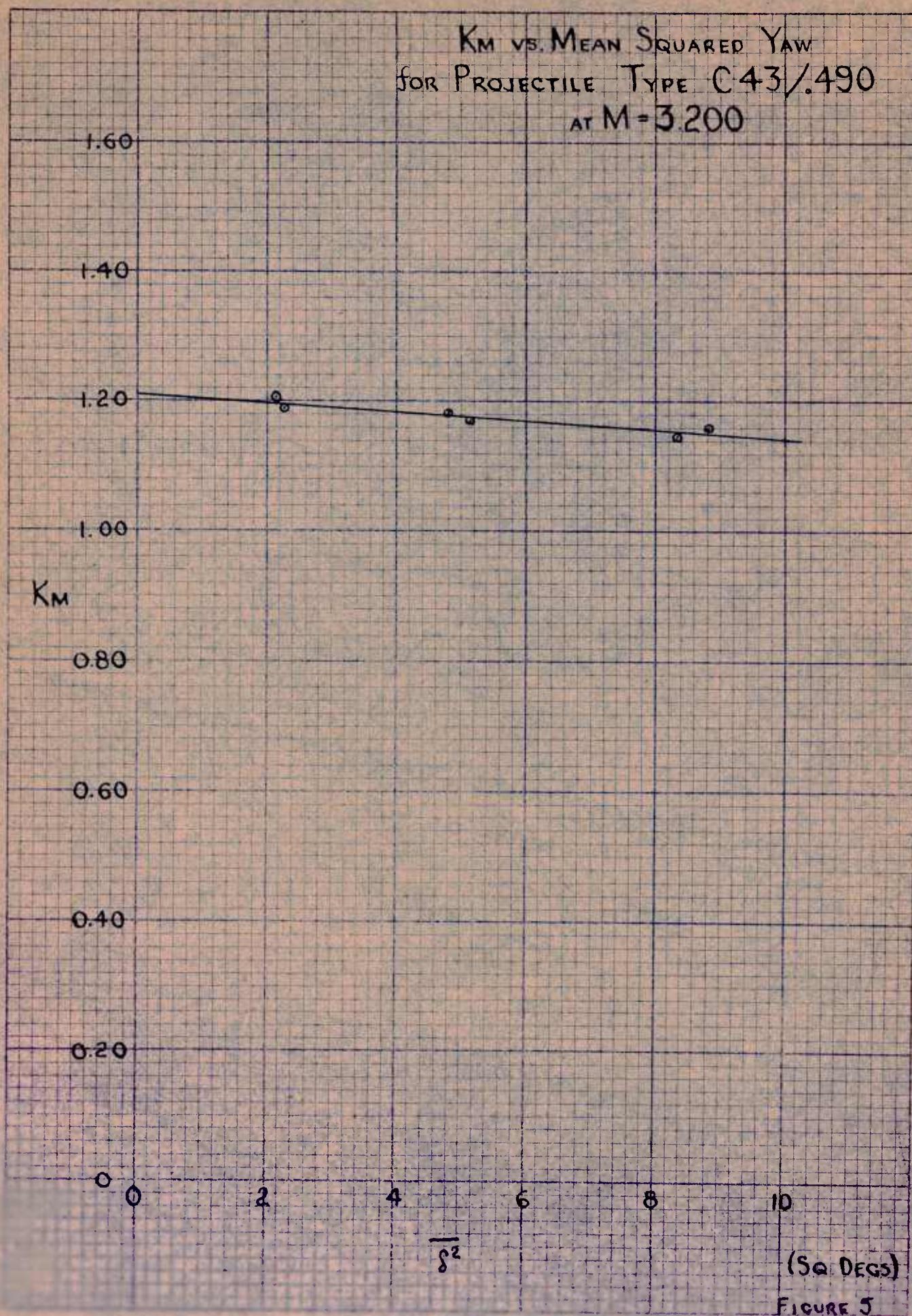


FIGURE 5